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Clinical Research

To Improve Your Surgical Drilling Skills, Make Use of Your Index Fingers

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Abstract

Background Surgery has greatly benefited from various technologic advancements over the past decades. Surgery remains, however, mostly manual labor performed by well-trained surgeons. Little research has focused on improving osseous drilling techniques. The objective of this study was to compare the accuracy and precision of different orthopaedic drilling techniques involving the use of both index fingers.

Questions/purposes (1) Does the shooting grip technique and aiming at the contralateral index finger improve accuracy and precision in drilling? (2) Is the effect of drilling technique on accuracy and precision affected by the experience level of the performer?

Methods This study included 36 participants from two Dutch training hospitals who were subdivided into three groups (N = 12 per group) based on their surgical

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experience (that is, no experience, residents, and surgeons). The participants had no further experience with drilling outside the hospital nor were there other potential confounding variables that could influence the test outcomes. Participants were instructed to drill toward a target exit point on a synthetic bone model. There were four conditions: (1) clenched grip without aiming; (2) shooting grip without aiming; (3) clenched grip with aiming at the contralateral index finger; and (4) shooting grip aiming at the contralateral index finger. Participants were only used to a clenched grip without aiming in clinical practice. Each participant had to drill five times per technique per test, and the test was repeated after 4 weeks. Accuracy was defined as the systematic error of all measurements and was calculated as the mean of the five distances between the five exit points and the target exit point, whereas precision was defined as the random error of all measurements and calculated as the SD of those five distances. Accuracy and precision were analyzed using mixed-design analyses of variance.

Results Accuracy was highest when using a clenched grip with aiming at the index finger (mean 4.0 mm, SD 1.1) compared with a clenched grip without aiming (mean 5.0 mm, SD 1.2, $p = 0.004$) and a shooting grip without aiming (mean 4.9 mm, SD 1.4, $p = 0.015$). The shooting grip with aiming at the index finger (mean 4.1 mm, SD 1.2) was also more accurate than a clenched grip without aiming ($p = 0.006$) and a shooting grip without aiming ($p = 0.014$). Shooting grip with aiming at the opposite index finger (median 2.0 mm, interquartile range [IQR] 1.2) showed the best precision and outperformed a clenched grip without aiming (median 2.9 mm, IQR 1.1, $p = 0.016$), but was not different than the shooting grip without aiming (median 2.2 mm, IQR 1.4) or the clenched grip with aiming (median 2.4 mm, IQR 1.3). The accuracy of surgeons (mean 4.1 mm, SD 1.1) was higher than the inexperienced group (mean 5.0 mm, SD 1.1, $p = 0.012$). The same applied for precision (median 2.2 mm, IQR 1.0 versus median 2.8 mm, IQR 1.4, $p = 0.008$).

Conclusions A shooting grip combined with aiming toward the index finger of the opposite hand had better accuracy and precision compared with a clenched grip alone. Based on this study, experience does matter, because the orthopaedic surgeons outperformed the less experienced participants. Based on our study, we advise surgeons to aim at the index finger of the opposite hand when possible and to align the ipsilateral index finger to the drill bit.

Level of Evidence Level II, therapeutic study.

Introduction

Drilling of bone is a skill that is learned in vivo over years during most surgical training programs without specific

emphasis or knowledge on the most accurate technique. Aimed point shooting is a classic technique for using handguns [5]. This instinctive method of shooting does not rely on aiming the gun using the sight. The index finger can instinctively and accurately aim at objects. It has a separate extensor tendon, and it can move more independently from the adjacent fingers [21]. When the index finger is used to aim the gun and the middle finger to pull the trigger (shooting grip), this will result in more accurate aiming [7]. We extrapolated this knowledge to predict that the shooting grip on the surgical drill hand piece might make aiming more accurate and precise. Gaze behavior and eye-hand coordination have also been examined extensively in challenging visual motor tasks [20]. Several studies have shown that we are able to locate objects with closed eyes with respect to our own body and especially to our hands [2, 3, 6, 14, 15]. Drilling, a complex goal-targeted movement, may be improved by the proprioception of the index finger of the opposite hand.

Rationale

There is little research on the actual practice of drilling. Most of the current literature focuses on the mechanical aspects of the drills used, but there is no consensus on bone drilling speed and force [17]. Furthermore, advice on the drilling techniques used by senior surgeons is mostly anecdotal and based on trial and error. Testing and implementing techniques that are already used in similar situations outside the operating room could improve intraoperative drilling results [10]. Positioning the index finger of the opposite hand just behind the aimed exit point when drilling in bone might improve the results as a result of the benefit of proprioception during procedures where there is no visual information such as in pelvic surgery. Furthermore, iatrogenic lesions resulting from overshoot might decrease attributable to the sensory feedback of the nearly penetrated bone, which can easily be felt at the tip of the surgeon's finger.

Therefore, we asked: (1) Does the shooting grip technique and aiming at the contralateral index finger improve accuracy and precision in drilling? (2) Is the effect of drilling technique on accuracy and precision affected by the experience level of the performer?

Materials and Methods

The experimental study was conducted at two hospitals in The Netherlands: one university hospital and one large teaching hospital. The study was approved by our hospital's review board.

Participants

Thirty-six members from both hospitals were divided into three groups. These groups consisted of (1) 12 orthopaedic surgeons (> 6 years of drilling experience); (2) 12 orthopaedic residents (< 6 years of drilling experience) with 2 to 6 years of orthopaedic training; and (3) 12 people with no practical orthopaedic experience (including researchers and medical interns; no drilling experience). None of the participants had that much experience outside the hospital with drilling that this could be a confounding variable nor did they routinely use the pistol grip or routinely drill toward the index finger of their opposite hand.

Description of Experiment

Drilling exercises were performed on standardized surrogate bicortical bone models. One set of bone models (that is, tibia and femur) (Sawbones®, Malmo, Sweden) was prepared per participant to complete all the drilling exercises. Each Sawbones was premarked in the same way. Both the starting point and aiming point consisted of a 3-mm diameter black dot millimeter surrounded by a color that matches the different techniques. The drilling trajectories and length of the

trajectories (that is, 3 cm) were the same for every Sawbones. A pistol grip cordless drill with similar technical specifications, weight, and outline as used in the operating room (that is, 10.8 V, 2 Ah, 1300 rpm) (Metabo, Nürtingen, Germany) was used with a standard 2.5-mm diameter AO surgical drill bit.

The four experimental drilling techniques were explained and illustrated with an image (Fig. 1). The first technique (that is, clenched grip without aiming; CG-) did not involve a different grip or use of the index finger of the opposite hand; the second technique (that is, shooting grip without aiming; SG-) only involved the shooting grip without the use of the index finger of the opposite hand; the third technique (that is, clenched grip with aiming; CG+) did not involve a different grip but the index finger of the opposite hand was used; and lastly, the fourth technique (that is, shooting grip with aiming; SG+) involved both the shooting grip and use of the index finger of the opposite hand. Following the instructions, participants were asked to start drilling at the starting point and to exit the bone as near to the marked aiming point as possible. Each participant followed the same sequence (for example, SG- after CG-, SG+ after SG-, CG+ after SG+, CG- after SG-), but to prevent an advantage of one technique, each participant had a different starting point in the sequence with a counterbalanced design for the number of starting conditions within each

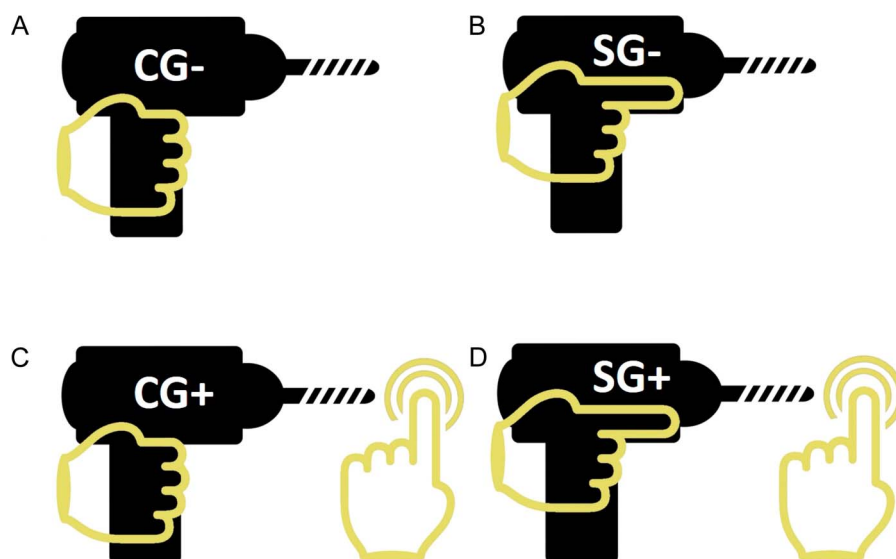


Fig. 1 A-D An overview of all techniques is demonstrated. **(A)** CG-: the dominant hand holds the drill with four fingers clenched without aligning the ipsilateral index finger (clenched grip). **(B)** SG-: the dominant hand holds the drill with three fingers clenched, and the index finger is used to help guide the trajectory (shooting grip). **(C)** CG+: the dominant hand holds the drill with four fingers clenched, and the index finger of the opposite hand is put at the aiming point. **(D)** SG+: the dominant hand holds the drill with three fingers clenched, and the index finger is used to help guide the trajectory while the index finger of the opposite hand is put at the aiming point.

group. The participants could drill a pilot hole at the starting point and have a look at the aiming point. Once they had started drilling, they were not allowed to have another look at the aiming point. The same researcher (CMER) was present at all tests. Each drilling technique had to be applied five times per set of femur and tibia (that is, 20 drill trajectories per test). To account for a possible test effect, the procedure was repeated after 4 weeks, preserving the counterbalanced design for the number of starting conditions.

Variables, Outcome Measures, Data Sources, and Bias

The experimental procedure resulted in five drilling holes per drilling technique per participant per session. The distances of the locations of the actual exit points of the five drilling holes in relation to the center of the target exit point were measured using a digital caliper (Digital Caliper 150 mm; Mitutoyo, Neuss, Germany) to determine the accuracy and precision of each attempt for each participant. Because the shape of the exit point was most of the time oblique instead of round, we measured and averaged the inner and outer borders (Fig. 2). The same researcher

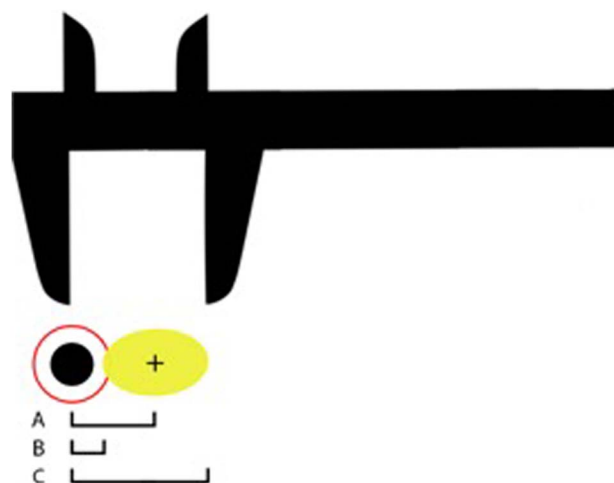


Fig. 2 The assessment of the distance toward the targeted exit point was measured using a caliper. The distance is marked as “A” (in millimeters). It measures the center of the targeted drilling exit point (black dot in the red circle) to the center of the actual drilling exit point (black plus in the yellow ellipse). To minimize measurement error, the distance for each exit point is measured by taking the sum of the distance between the center of the target and the inner (nearest) border of the drilling hole and the center of the target and the outer (farthest) border of the drilling hole divided by two ($A = [B + C]/2$). All measurements were in millimeters and all measurements were done by the same researcher (CMER) using the same caliper.

(CMER) performed each assessment to prevent any interobserver variability. Cohen’s κ statistic was calculated for intraobserver agreement. Distances between the actual exit point and the target exit point were used to determine the accuracy and precision of the drilling technique. Accuracy was defined as the systematic error of all measurements (that is, the systematic difference in distance between the actual exit point and the target exit point; Fig. 3) and was calculated as the mean of the five distances between the five exit points and the target exit point. Precision was defined as the random error of all measurements (that is, the random difference in distance between the actual exit point and the target exit point; Fig. 4) and was calculated as the SD of the five distances between the five exit points and the target exit point.

Statistical Analysis

Sample Size Calculation

An accuracy of < 2 mm was considered adequate and in line with what is generally acknowledged in the evidence [16]. With a power of 80% and an α of 0.05 to detect a systematic difference of 2 mm between the exit point and the target exit point with a measurement error of 1 mm [16], a minimum of 18 participants was required using a mixed-design analysis of variance (ANOVA) with the three experience groups and the four techniques as independent variables.

Statistical Analyses

The effect of drilling technique (clenched grip, shooting grip, aiming at index finger) on the accuracy and precision of orthopaedic drilling was examined with a four-way mixed-design ANOVA. Drilling technique and repetition (first and second sessions) were included as within-subject factors and hospital (university and teaching) and experience (orthopaedic surgeon, orthopaedic resident, inexperienced) were included as between-subject factors. Pairwise comparisons with Bonferroni correction were performed to examine differences between drilling techniques. One-way within- and between-subject ANOVAs with Bonferroni correction were used to examine the interaction effects, if significant. Partial eta squared (η^2) was used to determine the effect size. The assumption of normality was checked by visual inspection of histograms, q-q plots, and box plots of the data within the groups. Shapiro-Wilk tests were also performed on the data. Most of the precision data appeared not to be normally distributed; therefore, all precision data were transformed using a reciprocal transformation (by dividing one by each score

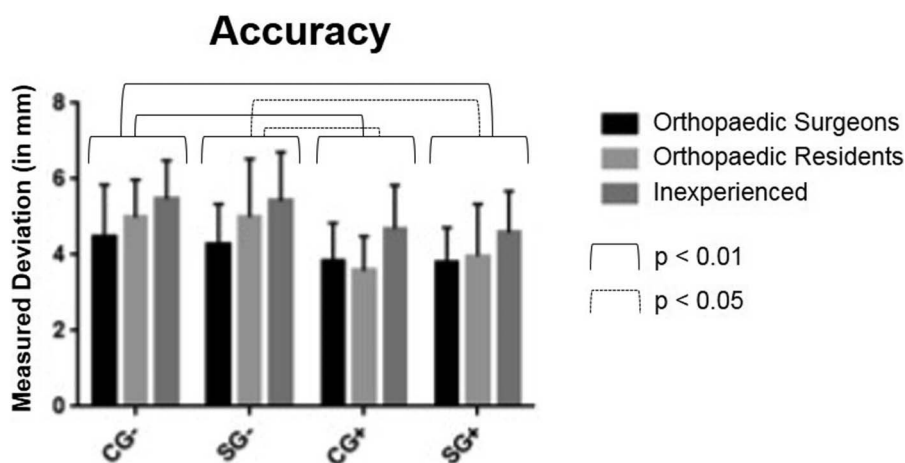


Fig. 3 This is an overview of the results of accuracy in drilling, expressed as the mean distance (mm) between the exit point and the target. Accuracy was defined as the systematic error. CG-: clenched grip without the use of the index finger of the opposite hand; SG-: shooting grip without the use of the index finger of the opposite hand; CG+: clenched grip with the use of the index finger of the opposite hand; SG+: shooting grip with the use of the index finger of the opposite hand. Error bars indicate 1 SD.

after adding 5 mm) on all precision data before statistical analyses. The assumption of sphericity was checked according to Girden [9]. With a Greenhouse-Geisser epsilon ≥ 0.75 , the Huynh-Feldt correction was used; otherwise, the Greenhouse-Geisser correction was used. Homogeneity of variance was checked using Levene's test and this assumption was not violated. All statistical analyses were performed using IBM SPSS 22.0 (IBM Software, Armonk, NY, USA) and a p value of < 0.05 was considered to be statistically significant.

Results

Effect of Drill Grip and Aiming on Accuracy and Precision in Drilling

Pairwise comparisons showed that accuracy was higher when using a shooting grip with aiming at the index finger (mean distance 4.1 mm, SD 1.2) as well as a clenched grip with aiming at the index finger (mean distance 4.0 mm, SD 1.1) when compared with a clenched grip without aiming

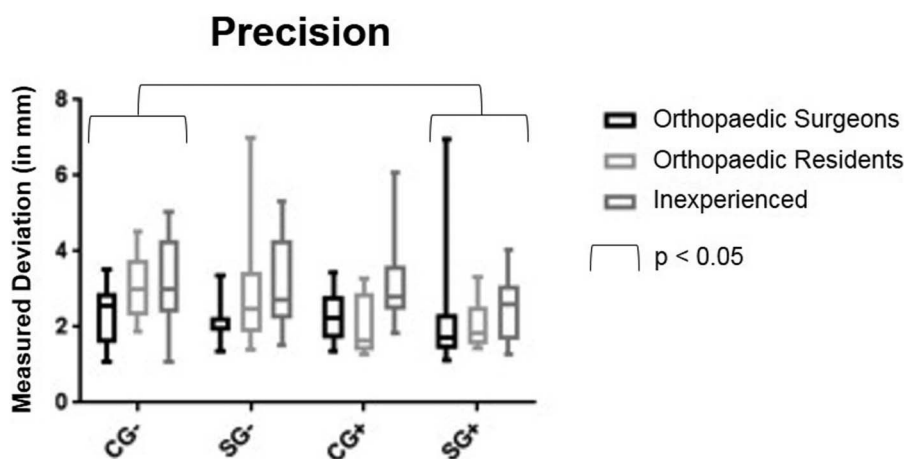


Fig. 4 This is an overview of the results of precision in drilling. Data of precision are visualized as a box plot and precision was defined as the random error and expressed as the mean SD of the distances (mm) between the exit points and the target. CG-: clenched grip without the use of the index finger of the opposite hand; SG-: shooting grip without the use of the index finger of the opposite hand; CG+: clenched grip with the use of the index finger of the opposite hand; SG+: shooting grip with the use of the index finger of the opposite hand.

(mean distance 5.0 mm, SD 1.2, $p = 0.006$ and $p = 0.004$, respectively) and shooting grip without aiming (mean distance 4.9 mm, SD 1.4, $p = 0.014$ and $p = 0.015$, respectively). The shooting grip with aiming at the opposite index finger (median 2.0 mm, interquartile range [IQR] 1.2) showed the best precision and outperformed clenched grip without aiming (median 2.9 mm, IQR 1.1, $p = 0.016$) but was not different than shooting grip without aiming (median 2.2 mm, IQR 1.4) and clenched grip with aiming (median 2.4 mm, IQR 1.3).

Does Surgical Experience Have an Effect on Accuracy and Precision in Drilling?

Orthopaedic surgeons outperformed the inexperienced group for accuracy (mean 4.1 mm, SD 1.1 versus mean 5.0 mm, SD 1.1, $p = 0.012$) and precision (median 2.2 mm, IQR 1.0 versus median 2.8 mm, IQR 1.4, $p = 0.008$). There was no interaction between drilling technique and experience ($F = 0.61$ [6.0–90.0], $p = 0.718$; $\eta p^2 = 0.04$).

There were no effects of hospital and repetition on the accuracy and precision of drilling. Cohen's κ statistic for intraobserver agreement was 0.81, which is considered excellent.

Discussion

Drilling bone is one of the most used skills in daily orthopaedic practice. Targeted movements such as drilling are guided by proprioceptive and visual information gathered by the brain. Many surgeons only rely on visual information and the proprioceptive information of the drilling hand [25]. However, there is little research on the manual technique of drilling. Most of the current literature in orthopaedic drilling focuses on the mechanical aspects of the drills used or on bone drilling speed and force. Residents gain their drilling skills in the operating room mostly based on advice of senior surgeons, which is mostly anecdotal and based on trial and error. The objective of the study was to examine the accuracy and precision of different orthopaedic drilling techniques.

This study has several limitations. First, we used softer Sawbones instead of harder, fresh frozen human cadavers. However, because all tests were performed on Sawbones, we do not expect that this altered the results. Second, the tests were performed on Sawbones with no surrogate soft tissue present. It was therefore easy to position one's index finger at the exit point, which may be more difficult or even impossible in vivo as a result of the soft tissue surrounding the bone. In such cases, the

drilling trajectory is longer compared with only bone or there might not even be enough physical space available to position the surgeon's finger, making it impossible to aim at the opposite index finger. There may also be an increased risk of compressing important structures against the exit point of the bone. However, aligning the ipsilateral index finger with the drill bit may still be possible. Third, the test environment was different from real-life situations in which the physician is more focused and takes more time per drilling trajectory to prevent iatrogenic damage. Although this may affect the intrapersonal variability, we believe that this does not affect the interpersonal variability and, therefore, does not influence the outcomes of this study. Fourth, the same researcher (CMER) was present during the tests and performed the measurements on the Sawbones to reduce interobserver variability. The measurements were performed at least 2 weeks after the tests and the Sawbones were blinded; thus, this was not a confounding variable. Last, with our proposed technique, it is not possible to secure drill sleeves after the drill grips. Drill sleeves protect the soft tissue, center the drill bit in an osteosynthesis plate, and help to position the drill until it grips. Sparrow et al. [23] correctly mention that lifting or pushing the drill sleeve alters the trajectory. When the surgeon aims at the index finger of his opposite hand, there is no hand left to hold the drill sleeve. However, a device that attaches the guide to the drill can be developed to resolve this problem. The differences in outcome among the techniques were small, but even small improvements in surgery should be pursued. This especially applies to drilling during surgery, because bone is surrounded with critical structures like arteries and nerves. Moreover, because drilling is usually used in trauma surgery, there can be a lot of small fragments that need to be fixed [22].

Effect of Drill Grip on Accuracy and Precision in Drilling

Our team devised four different drilling techniques, all of which involved the index finger of both hands. Our research showed that drilling results are improved by aligning the index finger with the drill bit and using the middle finger to pull the trigger while drilling toward the index finger of the opposite hand. This can be explained by the synergy between proprioception and visual information. In the brain, the cerebellum likely compares intended movements with actual ones and makes the necessary corrections [11]. Controlled movements occur in combination with the vestibular system. The distinct areas responsible for targeted movement on the human brain have been mapped. In a functional MRI study by Makin et al. [15],

specific areas of the brain (that is, intraparietal sulcus and lateral occipital complex) were identified representing nearby visual space with respect to the hands. In the somatosensory homunculus, the hand has the biggest proportion of all body parts on the primary motor and sensory cortex. This reflects tactile experience, voluntary movement, and kinesthetic proprioception [18]. The presentation of the fingertip in the somatosensory homunculus expands with tactile experience [19]. As a result of different innervation density, the fingertip has more tactile potential than the base of the finger [8]. Proprioception may thus be improved by additional proprioceptive information from the index finger of the drilling hand as well as the index finger of the opposite hand [25]. For future studies, it might be interesting to add timed experiments and experiments on inserting a screw through a predrilled hole, because small differences may lead to less fixation.

Does Surgical Experience Have an Effect on Accuracy and Precision in Drilling?

Senior surgeons with > 6 years of orthopaedic drilling experience had better outcomes compared with inexperienced individuals in both accuracy and precision, indicating that experience does matter. There was no effect of experience on drilling technique. This suggests that long-term experience in bone drilling does help obtain good results and that repetitive drilling of bone improves outcomes despite the lack of a short-term learning curve. This is in line with other studies such as the study of Jerjes and Hopper [13]. They also state that experience does matter but that many factors can influence the outcome of surgery and that experienced surgeons often perform more complex surgery than less experienced surgeons. Furthermore, Camp et al. [4] found that cadaveric skill laboratories improved the performance of residents compared with matched controls. Practicing one's techniques, partly outside the operating room, might speed up the time needed to obtain an acceptable and safe level of drilling in real-life circumstances [1, 12, 24, 26].

Conclusions

Based on this study, a shooting grip combined with aiming toward the index finger of the opposite hand is better for both accuracy and precision compared with a clenched grip alone. Differences between drilling techniques are not affected by experience, but experienced surgeons outperformed less experienced participants. Based on our study, we advise surgeons to aim at the index finger of the opposite hand where possible and to align the ipsilateral index finger to the drill bit.

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